









# NAVAL POSTGRADUATE SCHOOL

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An Interrogative Model  
of Computer-Aided Adaptive Testing:  
Some Experimental Evidence

by

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AN INTERROGATIVE MODEL OF COMPUTER-AIDED ADAPTIVE  
TESTING: SOME EXPERIMENTAL EVIDENCE

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### ABSTRACT

This thesis proposes and validates an interrogative diagnostic model of computer-aided, adaptive testing. The model uses an algorithm based on Bayesian techniques to determine both the number and the difficulty level of questions to present. The power of the model lies in its ability to automatically adapt a testing session to the individual's level of knowledge by choosing the domain, type and number of questions. The model was implemented as a computer program and was tested in an experiment with 34 military officers who were masters degree students. Analysis of the results indicated that the IDM can evaluate student knowledge as effectively as traditional written examinations but with a significantly less number of questions and shorter test duration.

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## I. INTRODUCTION

In education it is crucial to access objectively and accurately a student's level of proficiency. Computer-Aided Testing (CAT) is becoming one of the most effective evaluation tools available to the educator. The greatest challenge to developing computer-aided tests is modeling a testing session in an intelligent manner.

Most current computer-aided tests are based on enumerative or adaptive methods [Bejar 1986, Thomas 1986, Larson 1987]. Enumerative testing is similar to traditional written examinations in which an individual is asked a fixed number of predetermined questions. Adaptive testing on the other hand selects both the number and type of questions presented to the individual according to his personal skills and previously acquired knowledge.

This thesis proposes and validates a computer-aided testing model called the Interrogative Diagnostic Model (IDM). The model is both declarative and adaptive in nature. In other words, a pool of questions are explicitly stored in a test bank along with their difficulty level. The model uses an algorithm based on Bayesian techniques to determine both the number and the difficulty level of questions to present. The power of the model lies in its ability to automatically adapt a testing session to the

individual's level of knowledge by choosing the domain, type and number of questions.

The model was implemented as a computer program and was validated in an experiment with 34 subjects. Analysis of the results indicated that the IDM can evaluate student knowledge as effectively as traditional written examinations but with a significantly less number of questions and shorter test duration. Chapter II of the paper reviews related literature in the area of computer aided adaptive testing. Chapter III describes the IDM in detail. The subsequent chapter discusses the computer implementation of the model. Design and administration of the experiment is described in Chapter V. The statistical analysis of the results are presented in Chapter VI. Chapter VII concludes by stating the advantages and disadvantages of the model and suggesting directions for future.

## II. LITERATURE REVIEW

Although considerable work has been done in the area of computer-aided instruction, research in computer-aided adaptive testing has been sparse [Brown 1977, Clancey 1984, Clancey 1986, Davis 1983]. Weiss [Weiss 1977] described a number of strategies for adapting test items to individuals differing abilities. Tennyson and Ruthen [Tennyson 1977] verified that an adaptive strategy in selecting the number of instances needed to learn concepts was more efficient than either partially adaptive or non-adaptive strategies. Further evidence that adaptive testing has validity was presented in an experiment by Thathon and Kruawan [Thathon 1985] in which a self scoring, flexi-level adaptive testing procedure proved both effective and practical.

Bayesian statistical techniques have also been investigated in the adaptive testing. Sympson [Sympson 1978] applied Bayesian techniques to measure ability of candidates using a hypothetical 20 item adaptive test. Bayesian analysis has also been applied to illustrate the basic mathematical concepts involved in scoring multiple choice achievement/aptitude tests [Warm 1978, Vale 1981]. Further application of Bayesian analysis to adaptive testing was done by Sivasankaran and Bui [Sivasankaran 1986]. Their work provides a basis for the IDM.

Methods of interpreting a candidate's response and immediate modification of the test itself were discussed by McArthur and Chou [McArthur 1984]. Loyd [Loyd 1984] presented evidence that a two-stage adaptive testing procedure, in which the first stage routes the individual to second stage which focuses on the individual's ability level is a more precise measure than a single test. Bejar [Bejar 1986] describes a further development in adaptive testing in which the testing program not only decides the number of questions but also actually generates new questions based on the ability of the person being tested.

However no attempt has been made to investigate the effects of incorporating learning theory into computer-aided adaptive testing. The interrogative diagnostic model presented in this paper makes use of Bayesian techniques and incorporates a multi-stage testing procedure based on cognitive learning theory proposed by Kibler et al [Kibler 1970]. The experiment conducted using the IDM was patterned after the design of Thathon and Kruawan [Thathon 1985] in that a group of individuals was given both a written and a computer test covering the same topics and the results of the exams compared.



### III. THE INTERROGATIVE DIAGNOSTIC MODEL

#### A. INTERROGATIVE LEARNING MEASUREMENT

According to the learning theory proposed by Kibler et al. [Kibler 1970], an individual progresses through different levels of learning (Table 1). Levels 1 and 2 form the first phase in which the individual begins to recall or recognize information and be able to translate it from one form to another. These two levels draw heavily on the ability to memorize information. During the second phase of the learning process, levels 3 through 6, the individual assimilates and integrates information of increasing complexity.

The IDM has accordingly two types of questions which directly correspond to the these two phases of learning. These are the Supplementary and Critical questions. Supplementary questions are those questions which are basic in nature and cover levels 1 & 2. Critical questions are those questions which are advanced in nature and cover levels 3-6.

The rationale for the Interrogative Diagnostic Model (IDM) of testing is based on the dynamics of an oral examination. Before an oral examination, the examiner prepares a set of topics to be covered and within them identifies specific questions. But the difficulty level and

number of questions actually selected and presented during the examination are guided by the student's answers to previous questions. This type of interaction can best be modeled by incorporating Bayesian techniques. The IDM makes use of these techniques.

TABLE 1 COGNITIVE LEARNING LEVELS [Kibler 1970]

LEVEL	(Lowest - 1, Highest - 2)
1	KNOWLEDGE--recall or recognize information
2	COMPREHENSION--translate it from one form to another
3	APPLICATION--apply a known procedure to a new situation
4	ANALYSIS--break down information
5	SYNTHESIS--put information together
6	EVALUATION--evaluate something according to some criterion

#### B. MODEL EXECUTION STEPS

Figure 1 illustrates the model in the form of a flowchart. The model first formulates a hypothesis about a student's proficiency in a given topic area and then evaluates that hypothesis using a bank of questions. The model then derives conclusions about the student's knowledge.

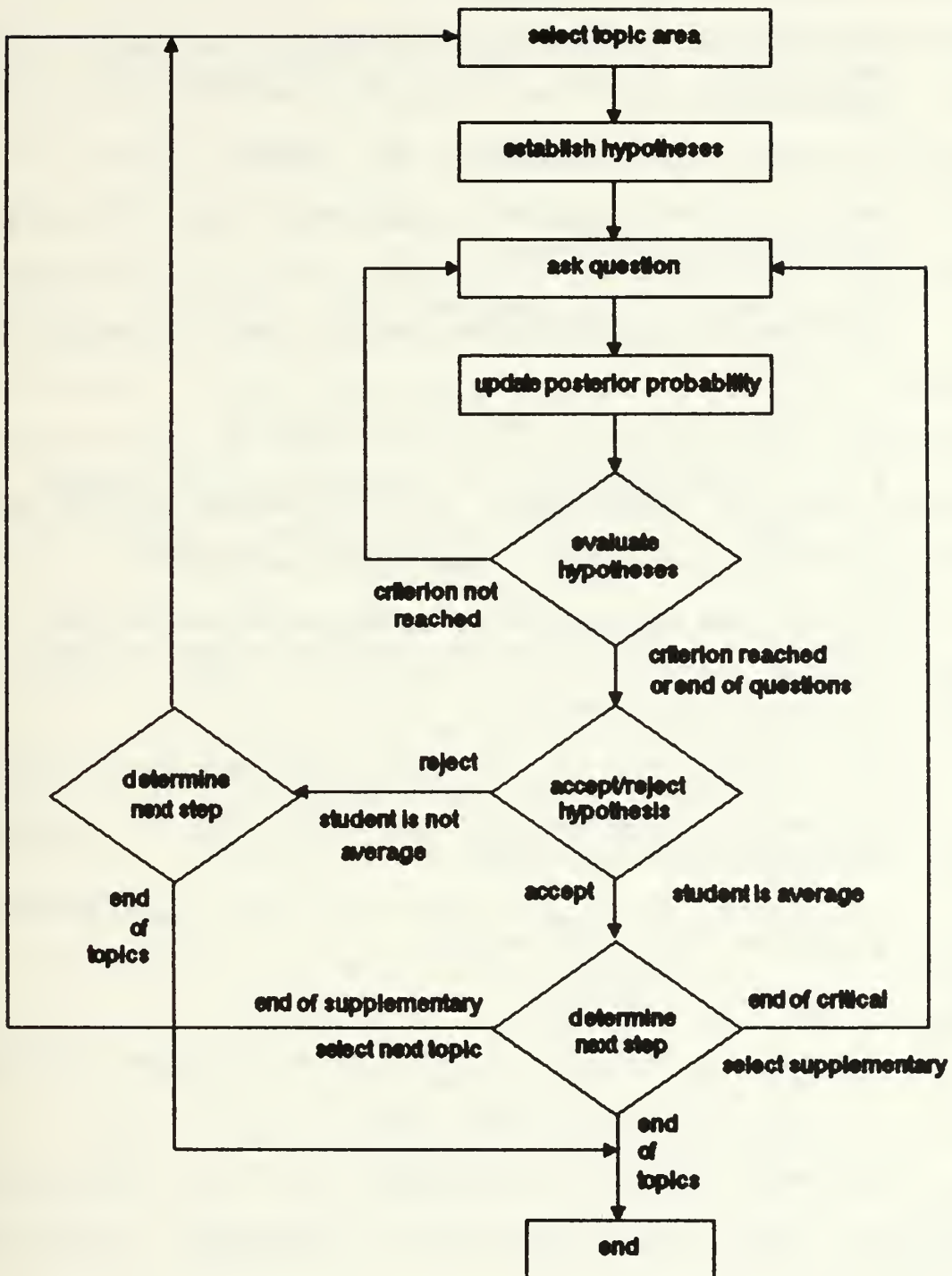


Figure 1 IDM Flow Chart

The IDM consists of eight steps:

1. A topic area is selected.
2. A hypothesis is made that the student is more likely an average student and a prior probability value initialized.
3. A question is presented to the student.
4. The student response is evaluated and the earlier probability is updated.
5. The probability is compared with evaluation criteria and further questions are asked if the criteria are not met.
6. The hypothesis is accepted or rejected.
  - a. If the hypothesis is rejected it is because the student is either above or below average and proceeds to step 8. In either case the model selects a new topic area in which to query the student.
  - b. If the hypothesis is accepted it is because the student is average and the model proceeds to step 7.
7. A decision is made to:
  - a. end the test if all topic areas have been covered.
  - b. select supplemental questions if the critical questions have been asked.
  - c. select the next topic if the supplemental questions have been asked.
8. A decision is made to:
  - a. end the test if all topic areas have been covered.
  - b. select the next topic area.

The Bayesian theory as applied in the interrogative diagnostic model steps shown above is presented in detail in Appendix A.

### C. BAYESIAN PROBABILITY AND QUESTION ORDERING

Since Bayesian probabilities are affected by the ongoing performance of the individual, the ordering of the different questions selected during the testing process can significantly affect the judgement about the students proficiency. Three general methods of question ordering are considered: decreasing difficulty, increasing difficulty and alternating sequence. If questions are presented in a decreasing order of difficulty, an average student encountering the more difficult questions at the beginning of a testing session might be inappropriately underevaluated since he would reach the cutoff threshold probability early. On the other hand, if the questions are presented in an increasing order of difficulty, the average student might tend to be judged brighter than he really is. A third method is to order questions in an alternating sequence of difficulty. Theoretically, several other methods are also possible.

The effect of the three orderings on the student evaluation is pictorially in Figure 2. The first graph shows the effect of a decreasing order of difficulty. From this graph it can be seen that the moving average of the difficulty does not move down as rapidly as the actual difficulty. Regions I, II, and III of the graph represent the level of difficulty that a poor, average and superior student could reasonably be expected to handle respectively.



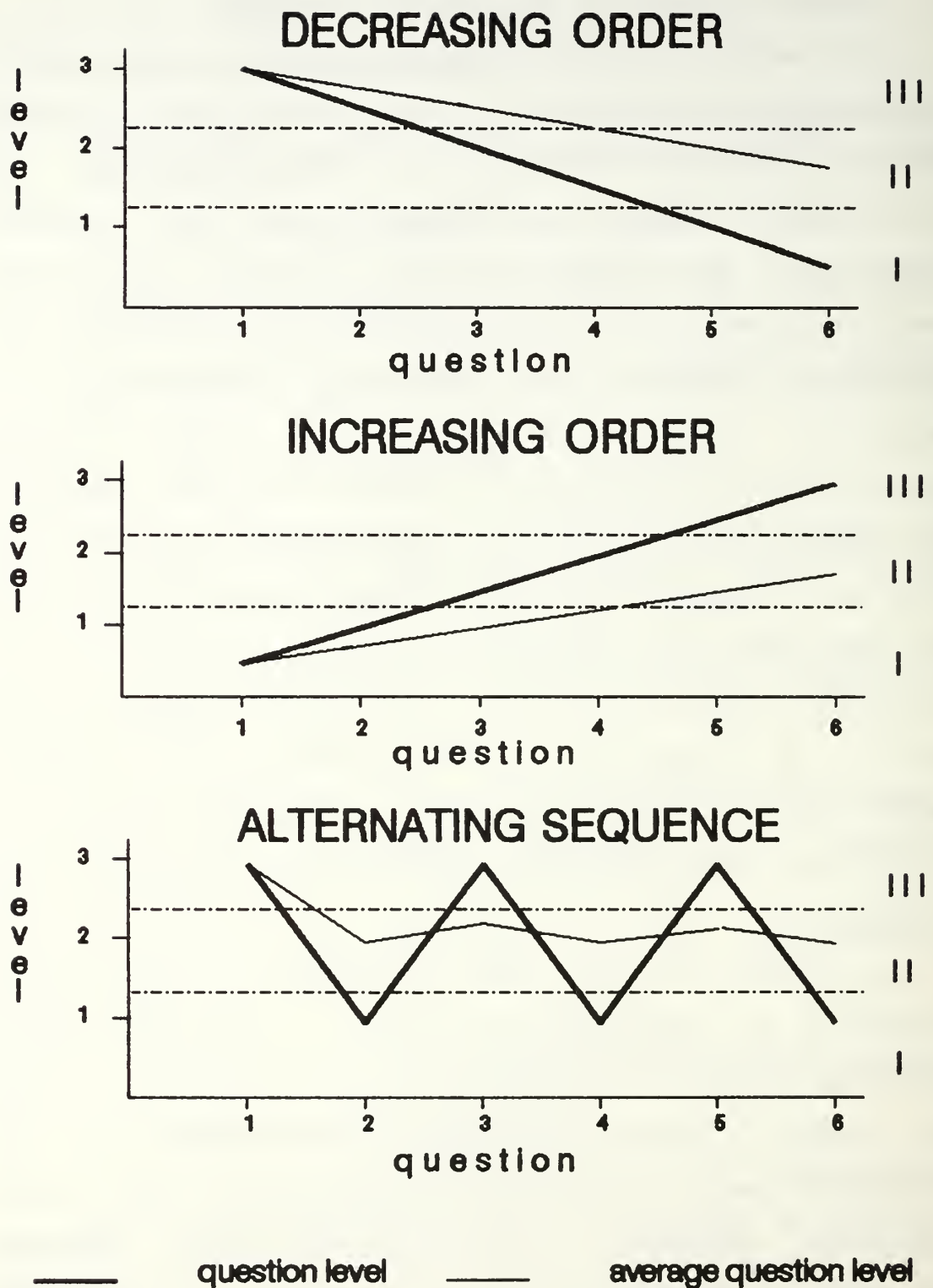


Figure 2 Effects of Different Question Ordering

In the first graph, the average difficulty level does not fall into the average region until the fourth question has been asked. By this time the Bayesian calculations may have already concluded that the student is poor when in reality he is average.

In a similar fashion the second graph, showing an increasing order in difficulty level might overrate an average student. In this case the average difficulty level is below the actual level and only when the fourth question is reached does the average difficulty level move into the region where the average student would be challenged. By the fourth question the Bayesian calculations may have concluded that the student is superior when he could be average.

The alternating sequence shown in the third graph overcomes the limitations of the previous orderings by alternating the question level. As can be seen the average difficulty level quickly moves into the average area and remains there with ever smaller oscillations. By remaining in the average area there is less likelihood that an average student will be under or over evaluated.

#### IV. IMPLEMENTATION OF THE DIAGNOSTIC MODEL

Implementation of the interrogative diagnostic model was divided into two main areas: program design and question design. Program design was closely allied with the first assumption and Bayesian statistical techniques presented earlier. The area of question design corresponded closely with the second assumption that questions can be written which test different levels of the cognitive domain.

##### A. PROGRAM DESIGN

The design of a program to implement the model was quite straight forward. dBASE III Plus was the language selected for implementation since the questions were easily stored and manipulated in a database. Because the specifications and structure of the program were not fixed, a prototyping approach was used in designing and writing the program. The final program consists of eight modules whose data flow diagram is shown in Figure 3.

The MAIN module retrieves criteria to be used in the Bayesian calculations, opens data files, selects topic areas, and calls subordinate modules. The INFO module presents the test instructions and gets student identification information. The ASK module presents questions to the student by calling the DOIT and QUESTION

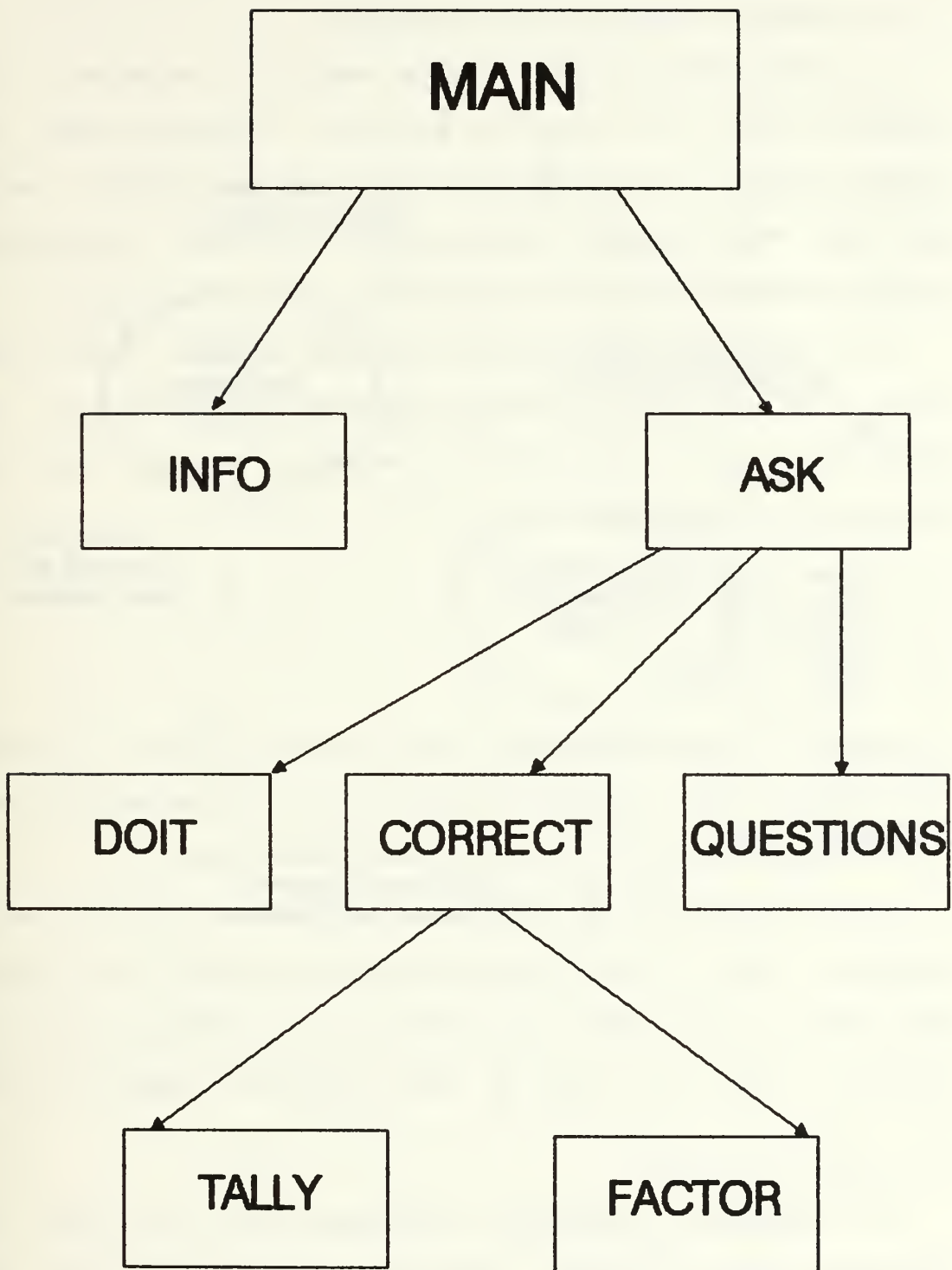


Figure 3 Program Structure Chart

modules in the case of critical questions or from data files in the case of supplemental questions.

The ASK module also forwards student's response to the CORRECT module for updating posterior probabilities. The FACTOR module calculates factorials for the CORRECT module and the TALLY module writes the question identification number, student answer and time taken to a data file.

The program evaluates the student in each topic area using the Bayesian technique presented in Appendix A. The numerical scores given by the computer program for each topic range as follows:

- 5 Superior
- 4 Above average
- 3 Average
- 2 Below average
- 1 Poor

A pictorial representation of the scoring process is shown in Figure 4. The student's total score for the entire exam is an average of the scores in each topic area.

Upon completion of coding the program was compiled using CLIPPER. This conversion allowed the program to execute appreciably faster and eliminated the the necessity for the student to begin the exam by first invoking dBASE III Plus.

## B. QUESTION DESIGN

In designing questions consideration was given to question type, content, cognitive level, ordering, and presentation. The types of questions used in the computer



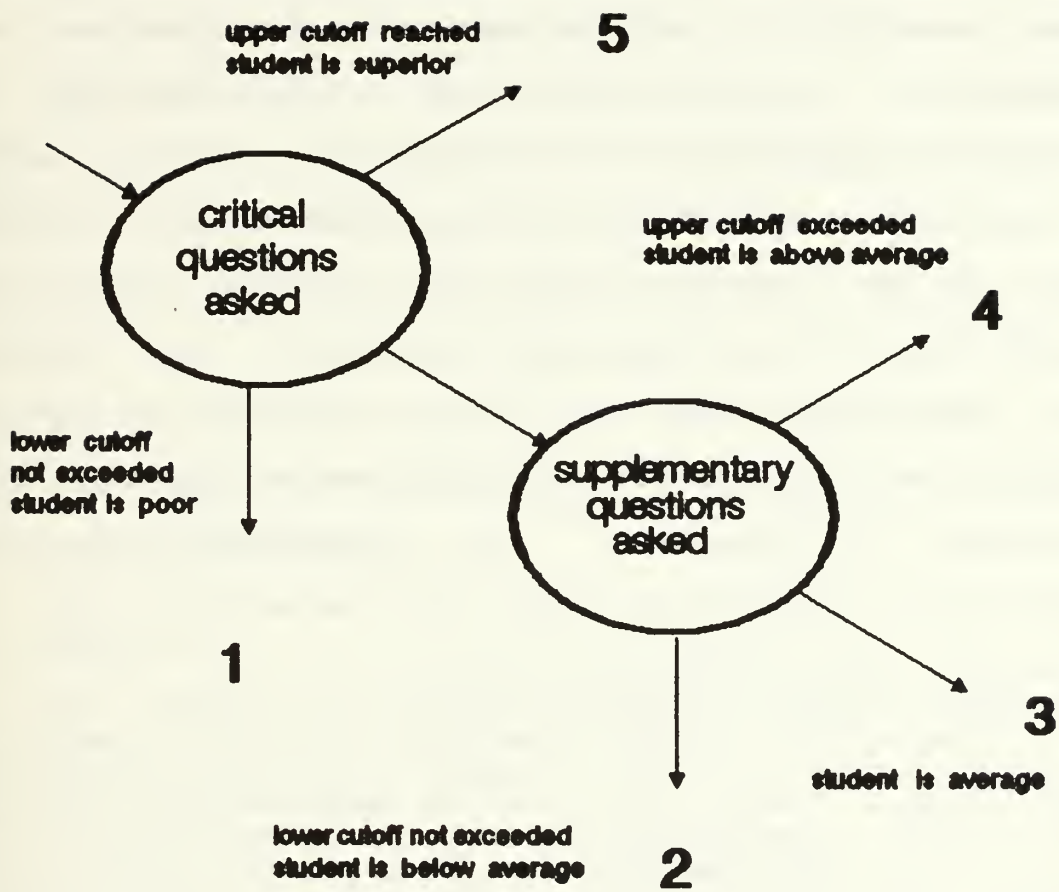


Figure 4 Computer Scoring Process

exam were limited to multiple choice and true/false. Due to the inability of the dBASE III Plus in processing natural language essay type questions were excluded. The content of the questions came from the textbook instructors manual, past examinations and the instructor. The questions were categorized by the instructor into critical and supplementary as discussed in Chapter III. However, instead of assigning a specific difficulty measure to each question, each question within a category was assigned one of three difficulty levels, with Level 1 being the least difficult and Level 3 being the most difficult. The text of both the critical and supplemental questions used in the program are presented in Appendix C. The alternating sequence of difficulty discussed in Chapter III was used to order the questions within a cognitive level.

Presentation of the questions to the subjects was challenging. Many of the critical questions were too long to fit on the standard 80 x 25 character screen. This problem was solved by partitioning each critical question into two program files. Dividing the critical questions into two screens meant that the students were required to page back and forth between screens to view a single question.

## V. RESEARCH DESIGN

### A. SETTING

A micro-computer lab equipped with 25 IBM PCs was used for administration of the computer exam. A diskette containing the compiled version of the computer exam was given to each student. A week prior to the actual exam a demonstration exam was given to the student in the same lab in order to let the student become familiar with the testing program. To further ensure that the students did not encounter any technical problems a facilitator was present during the examination.

### B. SUBJECTS

The subjects selected were masters degree management information systems students enrolled in a database management course at the Naval Postgraduate School. The subjects were of a homogenous background; all were junior military officers in their third quarter in the computer technology program. The course was divided into two sections of 21 and 13 individuals respectively, and the same instructor taught both sections.

### C. EXAM DESIGN

The subject area, database management, was divided into three topic areas, basic concepts, advanced concepts and

methodologies (normalization), and issues related to management of databases. Each topic area had 5 critical and 20 supplementary questions. Both the written and computer final examinations consisted of the same 75 questions (15 critical and 60 supplemental) and both had a two hour time limit. The written examination presented all 75 questions to the subjects and the questions were not grouped according to topic area or cognitive level. The computer exam presented a varying number of questions to the subject according to the Bayesian evaluation of the subject's previous answers. In the computer exam questions were grouped according to topic area. Upon finishing the exam each student was given a questionnaire to determine his reaction to the exam.

In order to compensate for any learning dynamics which could have influenced the responses from the first test to the second test, the experiment was conducted in the following manner. One section was given the computer-aided exam first, followed by the written exam. The other section was given the written exam first followed by the computer exam.

Upon finishing the exam each student was given a questionnaire to determine his reaction to the exam and to attempt to determine any other factors which might have

influenced his score. The questionnaire is presented in Appendix C.

#### D. HYPOTHESES

Based on the premise that recent developments in computer-aided testing tools would effectively evaluate students, the goal of the experiment was to focus on determining how such tools compare with traditional written examinations. More specifically, this experiment was designed to evaluate the validity of the Interrogative Diagnostic Model. The following hypotheses were tested:

- H1: The scores achieved by a student will be the same irrespective of whether the student takes the written or computer tests.
- H2: The evaluation quality both of the computer and of the written exam will be the same.
- H3: The number of questions presented to the student in the computer exam will be the same as the number of questions in the written exam.
- H4: The time taken to complete the computer exam will be the same as the time taken to complete the written exam.

#### E. HYPOTHESIS TESTING METHODOLOGY

In testing the above hypotheses, a factor analysis using the student's computer score, section and responses to the questionnaire was performed to identify dominant factors. A regression analysis was done with these factors as independent variables against the written exam score as the



dependent variable. In testing H1, the significance level of the coefficient of the computer score term was used. In addition, the written exam scores were converted to the computer scale and a difference in means test between the computer and written exam scores was conducted.

The evaluation quality (H2) for both the written final exam and the computer final exam was measured by comparing these scores with the average score of the student's two previous written examinations. This was considered an appropriate measure because the entire course consisted of three examinations with the third and final examination being comprehensive having only about 10 percent of new material.

Since the computer examination could theoretically present the same number of questions as the written examination, it was expected that the number of questions presented and time taken for the computer exam would be the same as those of the written exam. H3 was tested by counting the number of questions in the computer and written examinations and the two counts were compared using a difference in means test.

In testing H4, the times taken by the student for the computer exam and for the written were measured and compared using a difference in means test.



## VI. ANALYSIS OF EXPERIMENT RESULTS

The computer program automatically saved the exam responses, the computed score and the time taken by each student. In performing the factor analysis, eight variables were included to capture each of the following: 1) the computer score (COMPSCOR), 2) the section (SECTION), 3) inability to explain answers (XPLNANS), 4) lack of essay questions (NOESSYQ), 5) comfort level in using computers (COMFLVL), 6) perceived effectiveness (PCVDEFCT), 7) perceived pressure (PCVDPRES), 8) general feelings toward computer testing (GENLATT).

The factor extraction technique of principle axis factoring with varimax rotation was used. Items which failed to demonstrate convergent and discriminate ability by loading cleanly on a factor were deleted. The results of this analysis are reported in Table A. The items loaded on four factors. They were the computer score, the section, perceived effectiveness, and general discomfort with the concept of computer testing.

TABLE 2. VARIMAX ROTATED FACTOR MATRIX

Variable/Factor	1	2	3	4
SECTION	-0.32772	0.20560	0.85924	0.09138
COMPSCOR	0.05631	0.87267	0.21429	-0.12195
GENLATT	0.88687	0.04518	-0.12319	0.04472
XPLNANS	0.56898	-0.38634	0.15509	-0.46568
NOESSYQ	0.65517	-0.07445	0.63430	0.06525
PCVDPRES	0.79692	0.26031	-0.18654	0.11812
COMFLVL	0.09884	0.66550	-0.04637	0.35176
PCVDEFCT	0.10792	0.04534	0.12618	0.91199

Considering only variables with loads above 0.80, it can be seen that factor 1 loads on general feelings towards computer testing, factor 2 on the computer score, factor 3 the section and factor 4 on the perceived effectiveness of computer-aided exams.

Using the scores of these four factors as independent variables, a multiple regression was run against the the written exam scores. The results of this regression are shown in Table 3.

TABLE 3a. REGRESSION OF THE FACTORS AGAINST WRITTEN EXAM SCORE

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	60.766667	1.359042	44.7129	0.0000
FACTOR1	0.868266	1.382275	0.6281	0.5356
FACTOR2	7.751186	1.382275	5.6076	0.0000
FACTOR3	1.52467	1.382275	1.1030	0.2805
FACTOR4	-1.42072	1.382275	-1.0275	0.3140

R-SQ. (ADJ.) = 0.5094  
MAE = 5.356040

SE=7.443780  
DurbWat= 1.959

TABLE 3b. ANALYSIS OF VARIANCE FOR THE FULL REGRESSION

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	890.12	4	472.530	8.52791	.0002
Error	1385.25	25	55.4099		
Total (Cor.)	3275.37	29			

R-squared = 0.577071

Std. error of est. = 7.44378

R-squared (Adj. for d.f.) = 0.509403

Durbin-Watson statistic = 1.95859

From the table it is evident that factor 2 (computer score) is the only significant factor. A separate regression was therefore run using the computer score as the only independent variable. Results of this regression are shown in Table 4.

TABLE 4a. REGRESSION OF COMPUTER SCORE AGAINST WRITTEN EXAM SCORE

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	32.075889	3.67456	8.7292	0.0000
COMPSCOR	10.172458	1.251616	8.1275	0.0000

R-SQ. (ADJ.) = 0.6635

SE = 6.025962

MAE = 4.970321

DurbWat = 2.076

TABLE 4b. ANALYSIS OF VARIANCE FOR THE FULL REGRESSION

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	2398.63	1	2398.63	66.0556	.0000
Error	1161.99	32	36.3122		
Total (Corr.)	3560.62	33			

R-squared = 0.673655

R-squared (Adj. for d.f.) = 0.663456

Std. error of est. = 6.02596

Durbin-Watson statistic = 2.07571

The regression was rerun after transforming the written and the computer scores to a scale with origin (0,0) so that the constant term could theoretically be reduced to zero. For this smallest of the written and computer scores were subtracted from the original data. The effect of this transformation on the regression are shown in Table 5.

TABLE 5. REGRESSION OF COMPUTER SCORE AGAINST  
WRITTEN EXAM SCORE AFTER DATA  
TRANSFORMATION

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	4.248347	2.498387	1.7004	0.0987
COMPSCOR0	10.172458	1.251616	8.1275	0.0000
R-SQ. (ADJ.) = 0.6635		SE = 6.025962		
MAE = 4.970321		DurbWat = 2.076		

The computed t-value for the constant term is 1.7004. Since this is less than the critical value at 95 percent confidence level (1.960), the constant is statistically not significant. Thus it was considered appropriate to to disregard the constant term and to force the the regression line through (0,0). The results of this regression are presented in Table 6.

TABLE 6a. REGRESSION OF COMPUTER SCORE AGAINST WRITTEN  
EXAM SCORE AFTER DATA TRANSFORMATION AND  
DISREGARDING CONSTANT TERM

Independent	coefficient	std. error	t-value	sig.level
COMPSCOR0	12.110138	0.532355	22.7483	0.0000
R-SQ. (ADJ.) = 0.9401		SE = 6.196253		
MAE = 5.002530		DurbWat = 1.994		

TABLE 6b. ANALYSIS OF VARIANCE FOR THE FULL REGRESSION

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	19868.0	1	19868.0	517.483	.0000
Error	1266.99	33	38.39		
Total	21135.0	34			
R-squared = 0.940053					
Std. error of est. = 6.19625					
R-squared (Adj. for d.f.) = 0.940053					
Durbin-Watson statistic = 1.99362					

The the high values of R-squared, the F-ratio and the low mean square error tend to confirm that it is sound to model the computer score as an important factor influencing the written examination score. The difference in means test was also performed using the transformed data (Table 7). It can be seen that H1 cannot be rejected.



TABLE 7. TWO-SAMPLE ANALYSIS RESULTS

		Sample 1	Sample 2	Pooled
Sample	Number of Obs.	34	34	68
Statistics:	Average	2.99149	2.90776	2.94963
	Variance	1.86803	1.7982	1.83311
	Std. Deviation	1.36676	1.34097	1.35393
	Median	2.89474	3.2	3.11316

Difference between Means = 0.0837214

Conf. Interval For Diff. in Means: 95 Percent  
 (Equal Vars.) Smp11 - Smp12 -0.572049 0.739492 66 D.F.  
 (Unequal Vars.) Smp11 - Smp12 -0.572054 0.739496 66.0 D.F.

Ratio of Variances = 1.03884

Conf. Interval for Ratio of Variances: 0 Percent  
 Sample 1 v Sample 2

Hypothesis Test for H0:

Diff = 0 Computed t statistic = 0.254956  
 vs Alt: NE Sig. Level = 0.799549  
 at Alpha = 0.05 so do not reject H0.

The second hypothesis, that the computer exam would exhibit the same quality of evaluation as the written exam, was tested by comparing both the written exam scores and the computer exam scores with the average of the scores of two previous exams the students had taken. The rationale for this comparison was discussed previously in hypothesis testing methodology. The combined results of the two previous exams, called STUQUAL, served as the standard in determining quality. When the the written and computer scores were compared with STUQUAL, the constant term generated was not statistically significant and it was considered appropriate to disregard the constant and force the regression through zero. The results of this regression



are shown in Table 8. These results show an R-squared of 0.9809 for the written final exam and 0.9380 for the computer exam. Though there is a difference, it is considered slight, and based on these results, H2 cannot be rejected.

TABLE 8a. REGRESSION OF WRITTEN FINAL SCORE  
AGAINST PRIOR AVERAGE SCORE

Ind.variable	coefficient	std.error	t-value	sig.level
FINAL	1.426209	0.03463	41.1837	0.0000
R-SQ. (ADJ.) = 0.9809		SE = 12.437046		
MAE = 10.019345		DurbWat = 1.828		

TABLE 8b. ANALYSIS OF VARIANCE FOR THE FULL REGRESSION

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	262353.	1	262353.	1696.10	.0000
Error	5104.44	33	154.680		
Total		34	267457.		

R-squared = 0.980915  
R-squared (Adj. for d.f.) = 0.980915  
Std. error of est. = 12.437  
Durbin-Watson statistic = 1.82842

TABLE 8c. REGRESSION OF COMPUTER SCORE  
AGAINST PRIOR AVERAGE SCORE

Ind.variable	coefficient	std. error	t-value	sig.level
COMPSCOR	29.259444	1.308931	22.3537	0.0000
R-SQ. (ADJ.) = 0.9380		SE = 22.407366		
MAE = 17.488222		DurbWat = 1.516		

TABLE 8d. ANALYSIS OF VARIANCE FOR THE FULL REGRESSION

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	250888.	1	250888.	499.687	.0000
Error	16569.	33	502.09		
Total	267457.	34			

R-squared = 0.93805

R-squared (Adj. for d.f.) = 0.93805

Std. error of est. = 22.4074

Durbin-Watson statistic = 1.51624

Hypothesis 3, that number of questions presented to the student in the computer exam will be the same as the number on the written, was rejected. The written exam consisted of 75 questions. The number of questions asked by the computer ranged from 9 to 60. The average number of questions asked was 29. A difference in means test was performed comparing the number of questions asked by the computer exam with the number of questions in the written exam (Table 9). Results of the analysis show that H3 is rejected.

The fourth hypothesis to be tested was that the time taken to complete the computer exam would be the same as the time taken to complete the written exam. The times for both groups on each exam are shown in Table 10a. Because the questions in the computer exam were the same as those on the written exam, Section 1 students who took the written exam first, had seen all the questions the computer could theoretically ask. On the other hand Section 2 students, who had taken the computer exam first, had only seen a

TABLE 9. DIFFERENCE IN MEANS BETWEEN NUMBER  
OF COMPUTER ASKED QUESTIONS  
AND WRITTEN TEST

-----		NUMQUEST
Sample	Number of Obs.	34
Statistics:	Average	29.0588
	Variance	181.148
	Std. Deviation	13.4591
	Median	26
Confidence Interval for Mean:	95 Percent	
	Sample 1	24.3616 33.756 33 D.F.
Confidence Interval for Variance:	0 Percent	
	Sample 1	
Hypothesis Test for H0:		
	Mean = 75	Computed t statistic = -19.9033
	vs Alt: NE	Sig. Level = 0
	at Alpha = 0.05	so reject H0.
-----		

portion of the questions of the written exam. To avoid any learning/memory effects that could have occurred between the two exams, the written exam time of Section 1 was compared with the computer exam time of Section 2. A difference in means test was run on these times and the results are shown in Table 10b. Based on the results of this test H4 was rejected.

A summary of the results of this experiment are presented in Table 11.

TABLE 10a. AVERAGE EXAM TIMES (minutes)

	Computer Exam Time	Written Exam Time
Section 1	30	112
Section 2	53	83
Combined	39	101

TABLE 10b. DIFFERENCE IN MEANS BETWEEN COMPUTER AND WRITTEN EXAM TIMES

		CTIME	WTIME	Pooled
Sample	Number of Obs.	13	21	34
Statistics:	Average	52.7692	112.095	89.4118
	Variance	236.192	179.89	201.004
	Std. Deviation	15.3685	13.4123	14.1776
	Median	53	120	103.5

Difference between Means = -59.326

Conf. Interval For Diff. in Means: 95 Percent  
 (Equal Vars.) Smp11 - Smp12 -69.5199 -49.1322 32 D.F.  
 (Unequal Vars.) Smp11 - Smp12 -70.0266 -48.6254 22.9 D.F.

Ratio of Variances = 1.312983

Conf. Interval for Ratio of Variances: 0 Percent  
 Sample 1 v Sample 2

Hypothesis Test for H0:

Diff = 0 Computed t statistic = -11.8573  
 vs Alt: NE Sig. Level = 3.00426E-13  
 at Alpha = 0.05 so reject H0.

TABLE 11. SUMMARY OF RESULTS

H1: The scores achieved by a student will be the same irrespective of whether the student takes the written or computer tests.

NOT REJECTED

H2: The evaluation quality both of the computer and of the written exam will be the same.

NOT REJECTED

H3: The number of questions presented to the student in the computer exam will be the same as the number of questions in the written exam.

REJECTED

H4: The time taken to complete the computer exam will be the same as than the time taken to complete the written exam.

REJECTED



## VI. CONCLUSIONS

This thesis presented the Interrogative Diagnostic Model and an experiment designed to test its validity. The model provides an adaptive mechanism to tailor testing sessions to individual students. The results of the experiment indicate that the IDM is a reliable model in evaluating student performance. The results also show that the IDM effectively evaluates students in less time and with less questions than a written test.

The major benefits in using such a testing system of are more efficient use of students' and instructors' time and less frustration in test taking for both strong and weak students. With this type of testing strong students are not bored by having to answer questions which are beneath their level of learning and hand weak students are not frustrated by having to answer questions beyond their capabilities.

Further validation testing will be needed before widespread use is made of this model. Possible future model testing scenarios would be testing the model in a classroom situation in which both computer tests and written tests are actively used to grade students. The effects that computer interface has on student performance is also area of related research.



One possible area in which examinations based on the IDM might prove beneficial is placement testing in industry and the military. The IDM might also prove valuable when integrated with computer-aided adaptive instruction. However used, the model can ultimately prove to be an effective substitute for conventional diagnostic methods currently in use.

## APPENDIX A

### BAYESIAN APPROACH TO THE INTERROGATIVE DIAGNOSTIC MODEL

In applying Bayesian analysis to the steps of the Interrogative Diagnostic Model presented in Section 3, two assumptions are necessary [Sivasankaran 1986]. The initial hypotheses of step 2 are derived by considering these two assumptions. The first is that nothing is known about the subject and there is a 50-50 chance that the subject is average. This possibility reflects complete uncertainty and becomes the uninformed prior probability  $p_u = 0.50$ . The second assumption is that the student has been evaluated, either by a human instructor or historical trends, and that a better estimate on the subject is available. This better estimate is termed  $p_e$ . The degree of conviction in the uninformed versus the estimated assumptions is  $a:b$  where  $a$  and  $b$  are weights. Expressed in probability notation this becomes

$$P(B_u) = a/(a+b)$$

$$P(B_e) = b/(a+b)$$

where  $B_u$  denotes the strength of belief in the uninformed opinion and  $B_e$  the strength in the belief in the estimated opinion. These strengths form the initial hypotheses of step 2.

Let  $M$  be the number of questions asked in a given topic area. The number of questions answered correctly is  $C$  and each event is denoted  $E$ . The mathematical formulation is shown below.

$$P(E/B_U) = \binom{M}{C} p_U^C (1 - p_U)^{M-C}$$

$$P(E/B_E) = \binom{M}{C} p_X^C (1 - p_X)^{M-C}$$

Bayes theorem  $P(B/A) = P(B) P(A/B)/[P(B) P]$  may now be applied as follows:

$$P(B_U/E) =$$

$$(a/a+b) \binom{M}{C} p_U^C (1-p_U)^{M-C}$$


---

$$(a/a+b) \binom{M}{C} p_U^C (1-p_U)^{M-C} + (b/a+b) \binom{M}{C} p_X^C (1-p_X)^{M-C}$$

and,

$$P(B_X/E) = 1 - P(B_U/E)$$

where  $P(B_U/E)$  and  $P(B_X/E)$  represent the updated hypotheses that the student has correctly answered  $C$  out of  $M$  questions. Updating the hypotheses is done by steps 3 and 4 of the model. Step three asks the student a question and step 4 calculates the updated hypotheses based on the student's response.

Given the updated hypotheises there are two possible courses of action. The first is to compare the updated value of  $P(B_x/E)$  with upper and lower cutoff criteria. The upper cutoff criteria, alpha, represents the minimum strength of belief in the estimated opinion that is required to conclude that the students knowledge is good. If  $P(B_x/E)$  exceeds alpha, the student is judged knowledgeable enough in the topic area being evaluated that no further questions are needed. Conversely, the lower cutoff criteria, beta, represents the minimum strength of belief in the estimated opinion required to discern weak students. If  $P(B_x/E)$  does not exceed beta, the student is judged unknowledgeable in the topic area being evaluated and no further questions in that topic area are needed.

The second course of action is necessary when all the questions in the critical level have been asked and the updated hypothesis  $P(B_x/E)$  lies between alpha and beta. In this case the student is considered to have an average knowledge of the subject area and the model then proceeds to the lower level of supplementary questions in the same topic area or if all the supplemental questions have been asked, the model proceeds to a new topic area.

IDM step 5 compares  $P(B_x/E)$ , the revised estimated opinion, with the cutoff values and if neither of the cutoff criteria have been reached the model returns to step 4. If one of the criteria has been reached or there are no

questions remaining to be asked in the in the cognitive level, the model proceeds to step 6. Step 6 accepts or rejects the updated hypothesis based on the cutoff criteria. If student has exceeded the upper cutoff or has not exceeded the lower cutoff, the hypothesis that the student is average is rejected. This means that the student has been evaluated as either surerrior or poor and, in either case, the model proceeds to a new topic area by returning to step one. If the hypothesis is accepted step 7 will ask further supplementary questions to further define the students knowledge level or, if the supplenentary questions have been asked, will proceed to a new topic area.

## APPENDIX B PROGRAM LISTING

This appendix contains a listing to the dBASE III Plus program files which implementated the IDM. The appendix begins with a list of the memory variables and datafield names used in the program files. The programs IQ1P1.PRG and IQ1P2.PRG are an example of the programming method used to implement the two screen critical questions mentioned in Chapter IV. The program files using this method are referred to as QUESTION in the program structure chart of Figure 3.

### MEMORY VARIABLES

Variable	Representing
aa	degree of conviction in uninformed probability
aalfa	threshold for believing subject is above average
bb	degree of conviction in expert probability
bbeta	threshold for believing subject is below average
f	value of combinations returned from factor.prg
i	counter in factor.prg
k	temporary storage variable for (numasked - right)
kf	temporary storage variable for k!
moreq	flag indicating if further supplemental questions are needed
nf	temporary storage variable for numasked!



numasked	number of questions asked thus far of a certian topic and type
numcrit	number of critical questions of a given type
numsup	number of supplementary questions of a given type
PBUE	Bayesian probability of the uninformed opinion being correct given the event
PBXE	Bayesian probability of the estimated opinion being correct given the event
PEBU	probability of the event given the uninformed opinion
PEBX	probability of the event given the estimated opinion
rf	temporary storage variable for right!
right	number of questions answered from a given type and topic area
SBU	strength of belief in uninformed opinion
SBE	strength of belief in estimated opinion
stop	flag indicating if further critical questions are needed
temp	temporary storage variable used in factor.prg
wrong	number of questions answered incorrectly from a given type and topic area
u	uninformed prior probability that a subject is not average
x	expert's prior probability that a subject is above average

# DATAFIELD NAMES

Field Names	Remarks
A	degree of conviction in uninformed probability
ALFA	threshold for believing subject is above average
ANSWER	the answer to a particular question
AREA	the topic area of questions being asked
ASTART	the time the subject was presented a question
AFINISH	the time the subject answered the question
B	the degree of conviction in expert probability
BETA	threshold for believing subject is below average
CUTOFF	minimum percentage of supplemental questions the program will present to the subject
NAME	subjects last name
LEVEL	difficulty level of a particular question
PROGRAM1	the first page program of a critical question
PROGRAM2	the second page program of a critical question
PU	uninformed prior probability that a subject is not average
PX	expert's prior probability that a subject is above average
QNUM	question identifier
QUESTION	memo entry containing the question and multiple choice answers
SRESPONSE	the subjects answer to the question
SSN	last four digits of a subject's SSN for identification purposes
SUP	name of the DBF file containing the supplemental questions
TYPE	cognitive domain level of question being asked

\* Program...: MAIN.PRG  
\* Author...: PAT O'DONNELL  
\* Date.....: SPRING 1988  
\* Notice...: Copyright (c) 1988, PAT-SIV, All Rights  
\* Reserved  
\* Notes.....: THESIS

SET TALK OFF  
SET BELL OFF  
SET ESCAPE ON  
SET CONFIRM ON  
SET COLOR TO W+/B

\* This is the main program module for a computer aided  
\* testing program. This module calls initilaizes the  
\* criterion values, and then calls two other modules  
\* which do the work of the program.

aa = 0  
bb = 0  
aalfa = 0  
bbeta = 0  
areanum = 1  
X = 0  
U = 0  
ccutoff = 0

USE criterion  
STORE ALFA TO aalfa  
STORE BETA TO bbeta  
STORE A TO aa  
STORE B TO bb  
STORE PX TO x  
STORE PU TO u  
STORE CUTOFF TO ccutoff  
USE

SELECT 1  
USE blkboard

SELECT 2  
USE dbarea

CLEAR  
TEXT

WELCOME TO THE  
COMPUTER AIDED TESTING SECTION  
OF THE IS-4183 FINAL EXAMINATION

ENDTEXT  
@ 22,10  
WAIT

CLEAR  
DO INFO

STORE " " TO aarea  
SELECT 2  
GO TOP  
DO WHILE areanum <= 3  
STORE area TO aarea  
DO ASK  
SELECT 2  
areanum = areanum + 1  
SKIP  
ENDDO

CLEAR  
TEXT

ENDTEXT

\* EOF MAIN.PRG

\* Program...: INFO.PRG  
\* Author...: PAT O'DONNELL  
\* Date.....: SPRING 1988  
\* Notice....: Copyright (c) 1988, PAT-SIV, All Rights  
\* Reserved  
\* Notes.....: THESIS

SET TALK OFF  
SET BELL OFF  
SET CONFIRM ON

\* This program module introduces the program to the  
\* student, gives instructions on using the program and  
\* gets the student's name and last four digits of his  
\* SSN for scoring.

CLEAR  
TEXT

Good morning and welcome to an experiment in computer aided testing. The purpose of this experiment is to try and determine whether a computer, using a small bank of questions and Bayesian analysis, can determine an individual's knowledge level in a given subject area as effectively as a traditional written exam. The program presented here is not a mere test with a fixed number of questions to be answered. This program adjusts both the number and type of questions to the individual. Should this experiment prove successful, testing programs of this type could have broad application in educational, industrial and military environments.

ENDTEXT  
@22,10  
WAIT

CLEAR  
TEXT

INSTRUCTIONS: You will be shown a series of questions and the program will prompt you for the answer. Just type in your answer followed by a carriage return. Some questions are presented in two screens. You may page back and forth between screens by following the system

prompts. If you have any questions there will be someone in the lab to answer them.

IMPORTANT: Be aware that you must answer each question in order, in other words you cannot skip a question and return to it later.

Professor Sivasankaran will use the higher score between this computer aided test and your written exam, so this does "count."

Good luck!

ENDTEXT

@ 22,10

WAIT

CLEAR

SELECT 1

MNAME = ' '

MSSN = 0000

@ 10,10 SAY [Enter your lastname and last four digits of your]

@ 11,10 SAY [social security number in the appropriate blocks.]

@ 14,10 SAY " LASTNAME: "

@ 14,33 GET MNAME PICTURE "!!!!!!!!!!!!!!!!!!!!!!"

READ

@ 16,10 SAY " SSN: "

@ 16,29 GET MSSN PICTURE "####"

READ

APPEND BLANK

REPLACE NAME WITH MNAME, SSN WITH MSSN

RETURN

\* EOF INFO.PRG



```
* Program...: ASK.PRG
* Author...: PAT O'DONNELL
* Date.....: SPRING 1988
* Notice....: Copyright (c) 1988, PAT-SIV, All Rights
*             Reserved
* Notes.....: THESIS
```

```
SET TALK OFF
SET BELL OFF
SET CONFIRM ON
```

```
*      This program asks the student a series of critical
*      and complementary questions from the topic database
*      file. The program forwards the results of the
*      questioning to calculation modules for bayesian
*      analysis.
```

```
numsup = 00
numcrit = 5
nummasked = 00
stop = 'NO'
right = 00
moreq = 'NO'
STORE " " TO supp
STORE "C" TO type
STORE ' ' TO start
STORE ' ' TO finish
```

```
SELECT 3
USE &aarea
GO TOP
STORE sup to supp
```

```
DO WHILE .NOT. EOF() .AND. stop = 'NO'
```

```
    STORE program1 TO page1
    STORE program2 TO page2
    STORE " " TO response
```

```
    goback = "Y"
    DO WHILE goback <> "N"
        DO DOIT
    ENDDO
```

```
    @ 24,05 SAY "Your answer to question "
    @ 24,29 SAY page2
    @ 24,32 SAY " is: [one of a, b, c ...]"
    @ 24, 59 get response picture '!'
    READ
    @ 24,05 SAY "           You chose "
```

```

@ 24,25 SAY response
@ 24,26 SAY " Press ENTER to confirm "
@ 24,25 GET response PICTURE '!'
READ

STORE TIME() TO finish

IF response = answer
    right = right + 1
ENDIF

SELECT 1
APPEND BLANK
REPLACE qnum WITH page2
REPLACE sresponse WITH response
REPLACE astart WITH start
REPLACE afinish WITH finish
SELECT 3

numasked = numasked + 1
DO correct
SKIP

ENDDO

IF moreq = 'YES'

    SELECT 4
    USE &supp
    GO TOP

    DO WHILE .NOT. EOF()
        IF type = 'S'
            numsup = numsup + 1
        ENDIF
        SKIP
    ENDDO

    stop = 'NO'
    numasked = 0
    right = 0
    STORE ' ' TO suppnum
    GO TOP

    DO WHILE .NOT. EOF() .AND. stop = 'NO'

        IF type = 'S'
            STORE STR(RECNO(), 2, 0) TO suppnum
            CLEAR

```

```

STORE TIME() TO start
@ 3,10
? "          ", QUESTION
?
STORE ' ' TO response
@ 22,20 SAY "Your answer to question "
@ 22,44 SAY supp
@ 22,45 SAY "SQ      "
@ 22,47 SAY suppnum
@ 22,49 SAY " is "
@ 22,53 GET response PICTURE "!"
READ

```

```

@ 22,10 SAY "          You chose "
@ 22,30 SAY response
@ 22,31 SAY " Press ENTER to confirm      "
@ 22,30 GET response PICTURE "!'
READ

```

```

STORE TIME() TO finish

```

```

IF response = answer
    right = right + 1
ENDIF

```

```

SELECT 1
APPEND BLANK
REPLACE qnum WITH suppnum
REPLACE sresponse WITH response
REPLACE astart WITH start
REPLACE afinish WITH finish
SELECT 4

```

```

numasked = numasked + 1
DO correct
SELECT 4

```

```

ENDIF
SKIP

```

```

ENDDO

```

```

ENDIF

```

```

RETURN

```

```

* eof ask.prg

```

\* Program...: IQ1P1.PRG  
\* Author...: PAT O'DONNELL  
\* Date.....: SPRING 1988  
\* Notice...: Copyright (c) 1988, PAT-SIV, All Rights  
\* Reserved  
\* Notes.....: THESIS

CLEAR  
TEXT

Consider a STUDENT file with the following fields used  
in a file processing system:

Name	character	15
Rank	character	6
Address	character	20
City	character	10
State	character	2
Zip	numeric	5
Salary	numeric	5
Age	numeric	2

One of the records in the STUDENT file contains the  
following values:

Smith LCDR 202FranklinSt Monterey CA 93940 42000 33

ENDTEXT  
@ 24,10  
WAIT  
RETURN

\*EOF IQ1P1.PRG

\* Program...: IQ1P2.PRG  
\* Author...: PAT O'DONNELL  
\* Date.....: SPRING 1988  
\* Notice...: Copyright (c) 1988, PAT-SIV, All Rights  
\* Reserved  
\* Notes.....: THESIS

CLEAR  
TEXT

If the Postal authorities decided to increase the zip code length to six digits and the application program was so modified, John's salary (based on the existing data files) would:

- a. not change at all
- b. would increase by \$3
- c. would increase by \$100,003
- d. would increase by \$30,000
- e. would decrease by \$21997
- f. would decrease by \$40000
- g. None of the above is true

ENDTEXT  
RETURN

\*EOF IQ2P2.PRG

\* Program...: DOIT.PRG  
\* Author...: PAT O'DONNELL  
\* Date.....: SPRING 1988  
\* Notice...: Copyright (c) 1988, PAT-SIV, All Rights  
\* Reserved  
\* Notes.....: THESIS

SET TALK OFF  
SET BELL OFF  
SET CONFIRM ON

\* This is the program module which presents the  
\* critical questions to the student.

STORE " " TO goback

STORE TIME() TO start  
DO &page1  
DO &page2  
@ 24,5 SAY "Do you want to go back to the previous page?  
(Y or N)"  
@ 24,59 GET goback picture "!"  
READ

RETURN

\*eof DOIT.PRG



```

* Program...: CORRECT.PRG
* Author...: PAT O'DONNELL
* Date.....: SPRING 1988
* Notice...: Copyright (c) 1988, PAT-SIV, All Rights
* Reserved
* Notes.....: THESIS

```

```

SET TALK OFF
SET BELL OFF
SET CONFIRM ON

```

```

*      This program module calculates the Bayesian
*      probabilities of the student's correct answers.

```

```

CLEAR
f = 0
eval = 0

```

```

do FACTOR with numasked, right, f

```

```

SBU = aa/(aa + bb)
SBX = bb/(aa + bb)

```

```

PEBU = f * (u ** right) * ((1 - u) ** (numasked - right))
PEBX = f * (x ** right) * ((1 - x) ** (numasked - right))

```

```

PBUE = (SBU * PEBU) / ((SBU * PEBU) + (SBX * PEBX))

```

```

PBXE = 1 - PBUE

```

```

*@14,10 say "PBXE  = "
*@14,18 say PBXE
*@20,10
*WAIT

```

```

CLEAR

```

```

DO CASE
  CASE type = 'C' .AND. PBXE >= aalfa
    stop = 'YES'
    eval = 1
    DO tally
  CASE type = 'C' .AND. PBXE <= bbeta
    stop = 'YES'
    eval = 5
    DO tally
  CASE type = 'C' .AND. numasked = numcrit
    moreq = 'YES'
  CASE type = 'S'

```

```

  IF (numasked/numsup) >= ccutoff .AND. PBXE >= aalfa

```

```

        stop = 'YES'
        eval = 2
        DO tally
ENDIF

IF (nummasked/numsup) >= ccutoff .AND. PBXE <= bbeta
    stop = 'YES'
    eval = 3
    DO tally
ENDIF

CASE type = 'S' .AND. nummasked = numsup
    eval = 4
    DO tally

ENDCASE

RETURN

* eof correct.prg

```

\* Program...: TALLY.PRG  
\* Author...: PAT O'DONNELL  
\* Date.....: SPRING 1988  
\* Notice...: Copyright (c) 1988, PAT-SIV, All Rights  
\* Reserved  
\* Notes.....: THESIS

SET TALK OFF  
SET BELL OFF  
SET CONFIRM ON

\* This is the program module which appends the area  
\* evaluations to the blkboard file.

SELECT 1  
APPEND BLANK  
REPLACE name WITH aarea  
REPLACE ssn WITH eval  
SELECT 3

RETURN

\* EOF TALLY.PRG

```
* Program...: FACTOR.PRG
* Author...: PAT O'DONNELL
* Date.....: SPRING 1988
* Notice...: Copyright (c) 1988, PAT-SIV, All rights
* Reserved
* Notes.....: THESIS
```

```
PARAMETERS numasked, right, f
```

```
SET TALK OFF
SET BELL OFF
```

```
temp=1
i = 1
```

```
do while i <= numasked
    temp = temp * i
    i = i + 1
enddo
nf = temp
```

```
temp = 1
i = 1
```

```
do while i <= right
    temp = temp * i
    i = i + 1
enddo
rf = temp
```

```
temp = 1
i = 1
k = numasked - right
```

```
do while i <= k
    temp = temp * i
    i = i + 1
enddo
kf = temp
```

```
f = nf/(kf * rf)
```

```
* EOF FACTOR.PRG
```

## APPENDIX C QUESTION LISTING

This appendix lists the 75 questions contained in the written and computer final exams. The questions are divided into the three topic areas: introduction, normalization and management. Each topic area begins with five critical questions followed by twenty supplementary questions. The difficulty level of the question is indicated by a number from one to three. This difficulty level was determined by the expert opinion of the instructor based on his experience of the questions in previous quarters. The meaning of those numbers is as follows:

1 less difficult

2 average difficulty

3 very difficult

- The answer to each question is indicated by > or ^.

## INTRODUCTION QUESTIONS

### Introduction Critical Question 1

Level 3

Consider a STUDENT file with the following fields used in a file processing system:

Name	character	15
Rank	character	6
Address	character	20
City	character	10
State	character	2
Zip	numeric	5
Salary	numeric	5
Age	numeric	2

One of the records in the STUDENT file contains the following values:

Smith LCDR 202FranklinSt Monterey CA 93940 42000 33

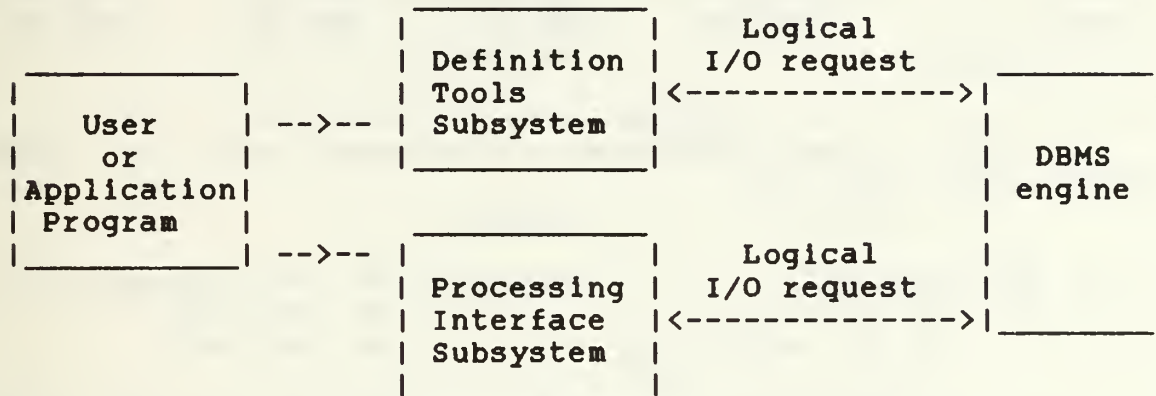
If the Postal authorities decided to increase the zip code length to six digits and the application program was so modified, John's salary (based on the existing data files) would:

- a. not change at all
- b. would increase by \$3
- c. would increase by \$100,003
- d. would increase by \$30,000
- > e. would decrease by \$21997
- f. would decrease by \$40000
- g. None of the above is true

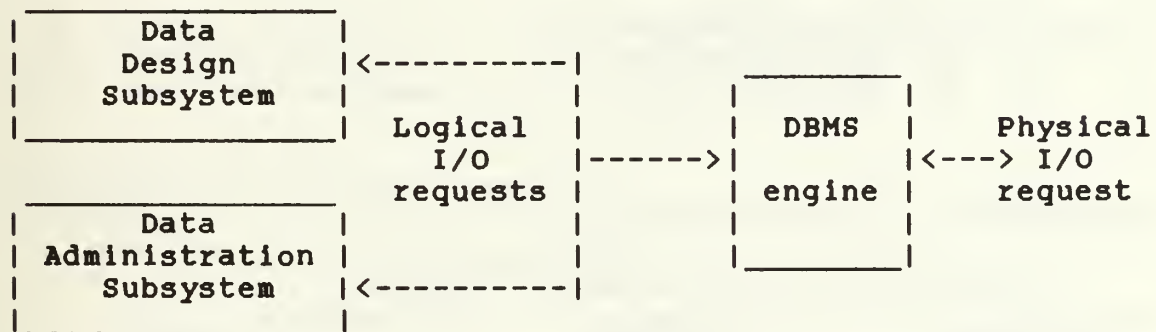


Which one of the following portrays accurately a subset of the functional components of a DBMS?

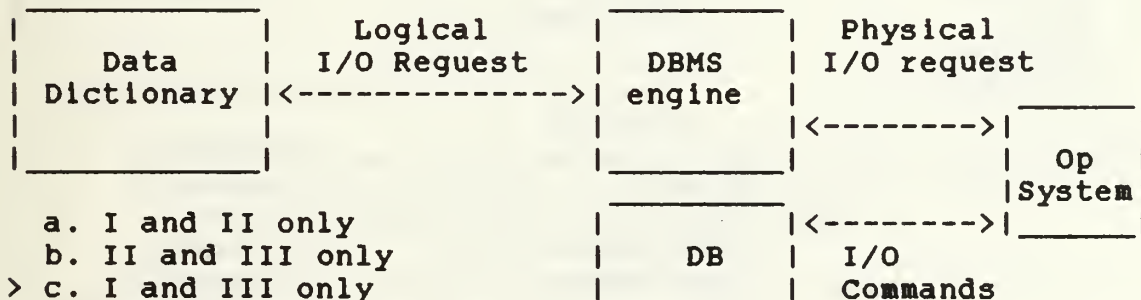
I.



II.



III.



- a. I and II only
- b. II and III only
- > c. I and III only
- d. III only
- e. all the above

## Introduction Critical Question 3

Level 3

The Prime Area of a storage that uses index sequential method contains the following records (in unblocked format):

Track 1	REC 5	REC 10	REC 15	REC 20
Track 2	REC 25	REC 30	REC 35	REC 40
Track 3	REC 45	REC 50	REC 55	REC 60

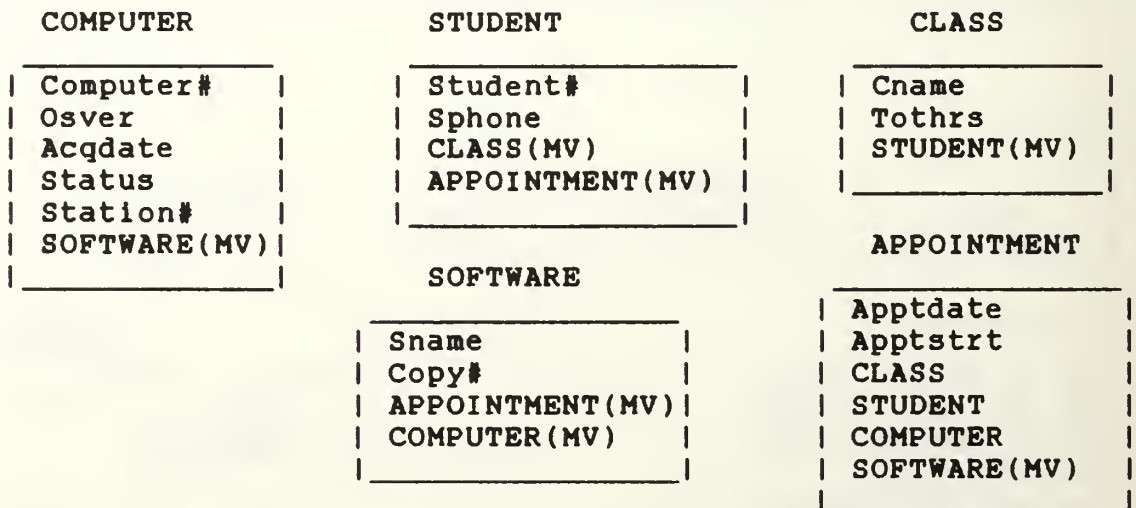
If REC 22 and REC 23 were to be added, the new track index would look like

a.	20	20	null	b.	1	20	22	address of 22
	2	40	40	null		2	40	40
	3	60	60	null		3	60	60
> c.	1	20	20	null	d.	1	20	22
	2	30	40	address of 35		2	40	35
	3	60	60	null		3	60	60
e.	1	20	20	address of 22				
	2	40	40	address of 33				
	3	60	60	null				

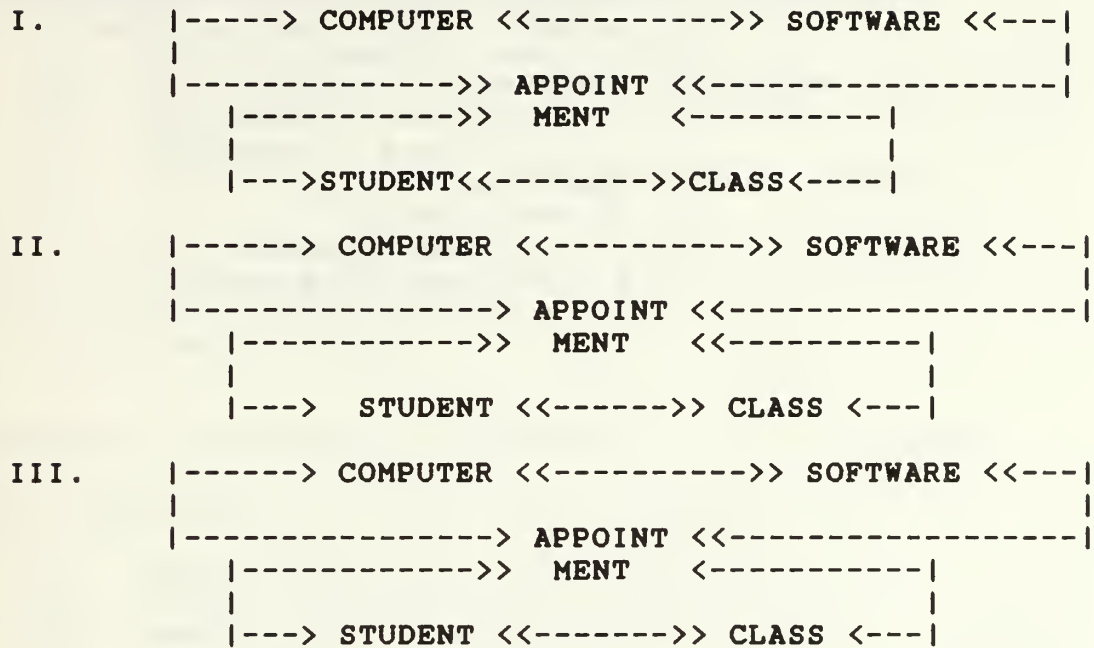
## Introduction Critical Question 4

Level 1

Consider the following object diagram:



The Bachman diagram for the above objects is given by:



- |                       |                             |
|-----------------------|-----------------------------|
| a. only I is true     | d. only II and III are true |
| b. only II is true    | e. all are true             |
| > c. only III is true | f. none are true            |

#### Introduction Critical Question 5

Level 1

Consider the following table:

	Scheduling	Inventory	Usage Analysis
Students	X		X
Class Rosters	X	X	
Computers			X
Faculty			X

Which of the following is true?

- I. Column I indicates the different applications in a database system and the remaining columns indicate files used by a DBMS.
- II. "X" indicates which file is used by which DB application.

III. Each column in the table is called a "schema".

IV. Column 1 indicates the different files and the remaining columns indicate applications.

V. The table is called a "schema".

- a. I, II, IV and V only
- > b. II, IV and V only
- c. II and IV only
- d. II, III and IV only
- e. All the above are true

Introduction Supplementary Question 1

Level 2

The disadvantages of file processing systems are:

- I. data is separated and isolated
  - II. data is often duplicated
  - III. application programs are dependent on file formats
  - IV. processing is slower than manual systems
- a. all the above
  - > b. I, II and III only
  - c. II, III and IV only
  - d. I and III only

Introduction Supplementary Question 2

Level 3

The functions of a DBMS engine include:

- I. build conceptual schema structure
  - II. manage disc and memory space
  - III. provide object and domain definitions
  - IV. map logical I/O requests into physical activity
- a. I and III
  - > b. II and IV
  - c. I, II and IV
  - d. all of the above
  - e. none of the above

Introduction Supplementary Question 3

Level 3

Whether a property is single- or multiple-valued has nothing to do with whether it is an object or nonobject property.

T or F

^

Introduction Supplementary Question 4

Level 2

Database data can be updated in different ways by a user:

- I. entering data via a load utility
- II. entering data with a form
- III. entering data in a tabular format
- IV. entering data through database views

- a. all of the above
- b. II, III and IV
- > c. I, II and III
- d. I, II and IV

Introduction Supplementary Question 5

Level 2

Some of the functions of a DBMS are:

- I. store, retrieve and update data
  - II. provide object and Bachman diagrams
  - III. provide coordination and control facilities for concurrent processing
  - IV. provide facilities for backup and recovery
- a. all the above
  - b. II and IV
  - c. I, II and IV
  - > d. I, III and IV

Introduction Supplementary Question 6

Level 3

Integrity rules are very easy to enforce using a DBMS

T or F  
^

Introduction Supplementary Question 7

Level 3

The domain of an object property is a set of object instances.

T or F  
^

Introduction Supplementary Question 8

Level 3

The fact that a property has multiple values does not imply that it must be an object property.

T or F  
^

Introduction Supplementary Question 9

Level 2

An OBJECT is a named collection of determinants that sufficiently describes an entity in the users work environment.

T or F <



Introduction Supplementary Question 10

Level 2

A set of attributes with the property that no two tuples in the relation can ever have the same values of these attributes is called the relation key.

T or F

^

Introduction Supplementary Question 11

Level 2

The Portion of an object that is visible to a particular application is called a VIEW.

T or F

^

Introduction Supplementary Question 12

Level 2

A complex relationship between two relations can be represented by including the key of one relation as an attribute in the other.

T or F

^

Introduction Supplementary Question 13

Level 1

The components of a database application are:

- I. hardware
- II. programs
- III. data
- IV. procedures
- V. personnell

- > a. all the above
- b. I, II, III and V
- c. I, II and III
- d. III, IV and V

Introduction Supplementary Question 14

Level 1

Some types of database data are:

- I. application data
- II. database metadata
- III. overhead data
- IV. transaction log data

- a. all of the above
- > b. I, II and III
- c. I and III only
- d. II and IV only

Introduction Supplementary Question 15

Level 1

The different phases of database system development are:

- I. definition
- II. requirement
- III. evaluation
- IV. design
- V. implement

- a. I, II, III and IV
- b. I, III, IV and V
- c. IV and V
- > d. all of the above

Introduction Supplementary Question 16

Level 1

Different attributes may take values from the same domain.

T or F  
^

Introduction Supplementary Question 17

Level 1

Each record in a relation is unique.

T or F  
^

Introduction Supplementary Question 18

Level 1

A relation is a flat file.

T or F  
^

Introduction Supplementary Question 19

Level 1

To be able to join two relations there must always be one common attribute.

T or F  
^

The `SELECT` operation defines a subset of tuples of a given relation (i.e. horizontal slice) based on a Boolean condition.

T or F

## NORMALIZATION QUESTIONS

Normalization Critical Question 1

Level 3

Consider the relation with the following structure:

STUDENT\_USAGE (SID, Computer\_Number, Class, Sname, Total\_Hours)

You are also given:

SID	----->>	Computer_Number
SID	----->>	Class
SID	----->	Sname
SID	----->	Total_Hours
Sname	--->	SID

Which of the following is false?

- I. SID and Sname are determinants but SID alone is the key
  - II. There is at least one transitive dependency leading to anomalies
  - III. There is exactly one MVD
  - IV. The relation can be upgraded to the next higher normal form by decomposing it into smaller relations
- > a. I, II and III  
b. II, III and IV  
c. I, II and IV  
d. all the above  
e. none of the above

## Normalization Critical Question 2

Level 3

Consider the following three relations with the given functional dependencies. Identify the normal form in which each relation is in.

R1 (A, C, B, D)	A ---> B
R2 (A, B, E)	AC ---> D
R3 (A, C, D, F)	A ---> E
	B ---> CD
	D ---> F

- |                      |                 |
|----------------------|-----------------|
| a. R1 - 2ndNF        | > b. R1 - 1stNF |
| R2 - 3rdNF           | R2 - BCNF       |
| R3 - 2ndNF           | R3 - 2ndNF      |
| c. R1 - 3rdNF        | d. R1 - 1stNF   |
| R2 - BCNF            | R2 - 3rdNF      |
| R3 - 2ndNF           | R3 - 2ndNF      |
| e. none of the above |                 |

## Normalization Critical Question 3

Level 3

Consider the relation S\_J\_T with three objects respectively; Student, Subject and Teacher. The following constraints apply:

- for each subject, each student of that subject is taught by only one teacher
- each teacher teaches only one subject
- each subject is taught by several teachers

Which of the following is true?

- |                                           |                        |
|-------------------------------------------|------------------------|
| I. S_J_T is in BCNF                       |                        |
| II. S_J_T has MVDs                        |                        |
| III. S_J_T has one possible composite key |                        |
| a. I only                                 | d. all of the above    |
| b. II only                                | > e. none of the above |
| c. III only                               |                        |

# Normalization Critical Question 4

Level 1

When these two relations are joined,

P#	PART COLOR	CITY
P1	red	LA
P2	blue	NY
P3	green	SF
P4	blue	NY

S#	P#
S1	P1
S1	P2
S2	P1

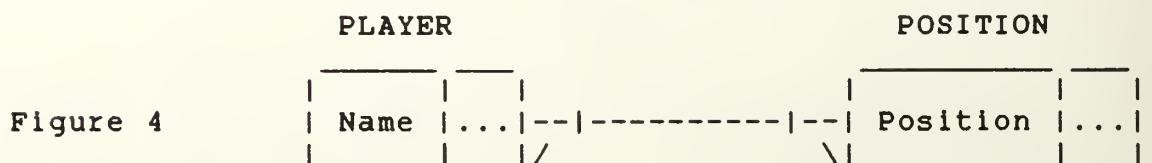
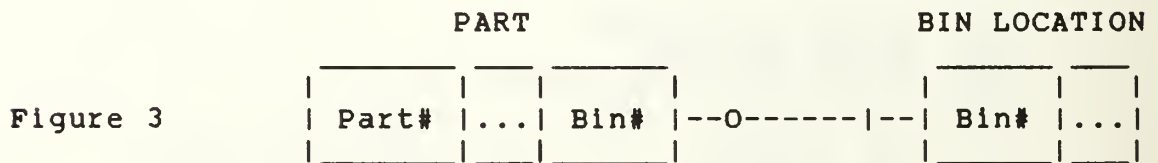
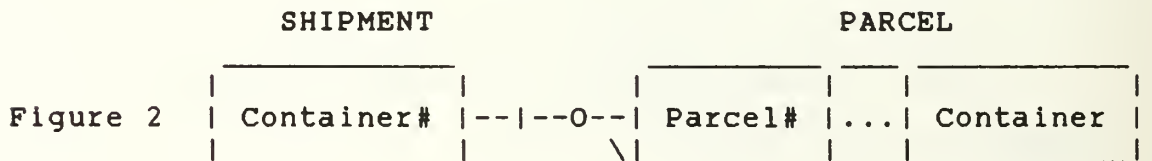
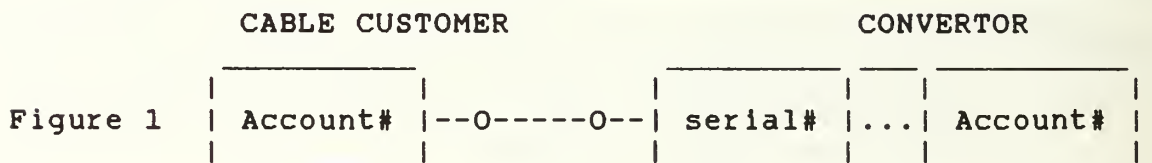
Which one of the following is true?

- a. there will be exactly 12 tuples in the resultant join
- > b. there will be exactly 3 tuples in the resultant join
- c. there will be exactly 4 tuples in the resultant join
- d. there will be exactly 7 tuples in the resultant join
- e. none of the above

# Normalization Critical Question 5

Level 1

Given the relations below:





Which of the following is true?

- I. Fig 1 represents an optional-optional relationship
- II. Fig 2 represents a mandatory-optional relationship
- III. Fig 3 represents an optional-mandatory relationship
- IV. Fig 4 represents a mandatory-mandatory relationship

- > a. I and IV only
- b. II and III only
- c. I, II and III only
- d. I, II and IV only
- e. all the above are true

Normalization Supplemental Question 1

Level 3

A loss projection occurs when

- > a. false data is generated by a projection
- b. a projection loses attribute values
- c. a projection loses tuples
- d. a projection cannot be made on two specific relations

Normalization Supplemental Question 2

Level 3

Which one of the following is true in one to one relationships?

- I. Attributes that have a one to one relationship must occur together in at least one relation. (call the relation R and the attributes A and B)
  - II. Both A and B must be part of the key of R.
  - III. An attribute can be added to R if it is functionally determined by A or B.
  - IV. A and B must occur together in R, but should not occur together in other relations.
- a. I, II and III
  - > b. I, III and IV
  - c. II and III
  - d. all of the above

Normalization Supplemental Question 3

Level 3

When evaluating database design

- a. machine efficiency has highest priority
- b. elimination of modification anomalies has the highest priority
- c. relation independence has the highest priority
- > d. priorities will be different depending upon requirements

Normalization Supplemental Question 4

Level 2

Primary keys must be unique within a relation but candidate keys do not have to be unique within a relation.

T or F <

Normalization Supplemental Question 5

Level 3

In the following functional dependancy  $A \rightarrow B \rightarrow C$ ,

- a. the dependancy is a multivalued dependancy
- > b. C is a transitive dependancy with A as its determinant
- c. C is the determinant
- d. A and C are not dependent

Normalization Supplemental Question 6

Level 2

If a relation is in domain key normal form, it

- > a. could have no modification anomalies
- b. may still have transitive dependencies
- c. could still have join dependencies
- d. could still have multivalued dependencies

Normalization Supplemental Question 7

Level 3

A relation in first normal form can generally be placed in second normal form by

- > a. projections
- b. joins
- c. selections
- d. products

Normalization Supplemental Question 8

Level 3

An interrelation constraint exists when

- > a. two or more relations share the same attribute
- b. two attributes in the relation have the same determinant
- c. two determinants in a relation have the same subject attribute
- d. two or more attributes of a candidate key have different determinants

Normalization Supplementary Question 9

Level 3

A modification anomaly occurs when change to one entity causes a change to a second entity.

T or F <

Normalization Supplemental Question 10

Level 3

Multivalued dependencies occur when

- a. several attributes are dependent upon the same determinant
- b. a single attribute has several determinants
- c. there are several transitive dependencies
- > d. several independent attributes are dependent on one other attribute

Normalization Supplemental Question 11

Level 3

Which of the following is not a relational design evaluation criterion:

- a. elimination of modification anomalies
- b. relation independence
- > c. ease of use
- d. reduction of key attributes

Normalization Supplemental Question 12

Level 3

Attributes that have a many to many relationship can exist together in a single relation (although this would create redundancies). Assume two such attributes E and F, residing together in a relation T.

Which of the following is false?

- I. The key of T must be E
  - II. The key of T must be F
  - III. Both E and F can be candidate keys
  - IV. An attribute can be added to T if it is determined by E or F
- a. I only
  - b. II only
  - c. III and IV only
  - > d. all the above
  - e. none of the above

Normalization Supplemental Question 13

Level 1

A relation is in domain/key normal form when

- a. the domain of the key is the function of the key
- b. the key is the function of the domain
- c. it has no multivalued dependencies
- > d. every constraint is a logical consequence of the definition of keys and domains

Normalization Supplemental Question 14

Level 1

If a relation is in third normal form, it must be in second normal form.

T or F

^

Normalization Supplemental Question 15

Level 1

A relation is in Boyce-Codd normal form if

- a. it has only one key
- b. it has no transitive dependencies
- > c. every determinant is a candidate key
- d. there are no deletion anomalies

Normalization Supplemental Question 16

Level 1

If a tuple cannot be inserted into a relation until an additional fact about another entity is known, it is referred to as:

- a. a deletion anomaly
- > b. an insertion anomaly
- c. a functional dependency
- d. an insertion redundancy

Normalization Supplemental Question 17

Level 1

If a relation meets the criterion that all nonkey attributes are dependent upon all of the key, it must be in:

- > a. second normal form
- b. fourth normal form
- c. domain/key normal form
- d. Boyce-Codd normal form

Normalization Supplemental Question 18

Level 1

In the following functional dependency  $A \rightarrow B \rightarrow C$ , the determinant(s):

- a. is A only
- b. is C only
- > c. are A and B
- d. are B and C

Normalization Supplemental Question 19

Level 1

Multivalued dependencies always exist in pairs.

T or F  
^

Normalization Supplemental Question 20

Level 1

If an attribute is a key it must be a determinant.

T or F  
^



## MANAGEMENT QUESTIONS

### Management Critical Question 1

Level 3

You are given this transaction log at the time the database crashed.

Relative  
Record  
Number

1	OT1	0	2	11:42	START			
2	OT1	1	4	11:43	MODIFY	CUST100	(old value)	(new value)
3	OT2	0	8	11:46	START			
4	OT1	2	5	11:47	MODIFY	SP AA	(old value)	(new value)
5	OT1	4	7	11:47	INSERT	ORDER 11		(value)
6	CT1	0	9	11:48	START			
7	OT1	5	0	11:49	COMMIT			
8	OT2	2	0	11:50	COMMIT			
9	CT1	6	10	11:51	MODIFY	SP AA	(old value)	(new value)
10	CT1	9	0	11:51	COMMIT			

Which of the transactions will be reprocessed after the last save?

- I. OT1
- II. OT2
- III. CT1

- a. I only
- b. II only
- c. III only
- d. all of the above
- > e. none of the above

There are three users in a multiuser DB. Each wants to perform the following sequence of events.

USER A	USER B	USER C
-----	-----	-----
Read rec 100	Read rec 200	Read rec 200
Change rec 100	Change rec 200	Change rec 200
Write rec 100	Write rec 200	Write rec 200

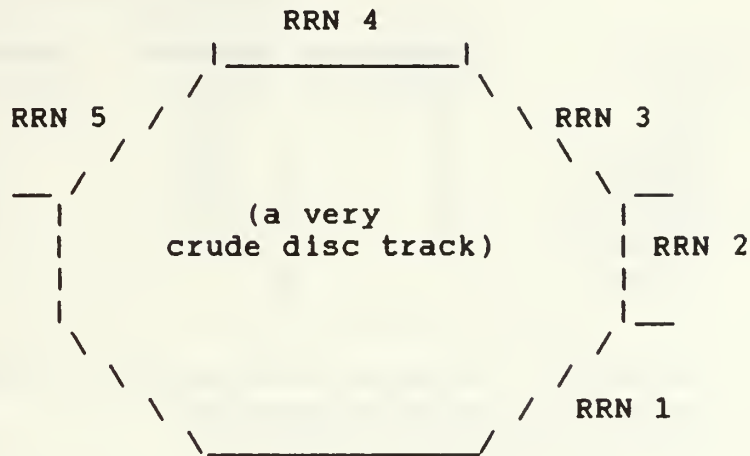
Which of the following sequences violates serializability?

I.	II.	III.
Read 100 for A	Read 200 for B	Read 200 for C
Read 200 for B	Read 100 for A	Change 200 for C
Change 100 for A	Change 100 for A	Read 100 for A
Write 100 for A	Write 100 for A	Write 200 for C
Read 200 for C	Change 200 for B	Change 100 for A
Change 200 for B	Read 200 for C	Read 200 for B
Write 200 for B	Change 200 for C	Change 200 for B
Change 200 for C	Write 200 for C	Write 100 for A
Write 200 for C	Write 200 for B	Write 200 for B

Select your answer:

- > a. I and II only
- b. II and III only
- c. I and III only
- d. III only

Five records are stored physically on a disc track as shown below:



The actual contents of each record is given in the following table:

RPN	SUPNAME	PARTID	PRICE
1	Topnotch	P003	9.95
2	Ugo	P014	0.99
3	Bestparts	P020	29.95
4	Acme	P008	99.99
5	Gotcha	P002	11.00

Assume you access the data in the following ways:

- I. Access the entire file in the order specified by a linked list created according to ascending order (alphabetic) by Supname.
- II. Access the entire file in the order specified by a linked list created according to ascending order (numeric) by PartID.

Assuming the disc rotates in a clockwise direction, which of the following is true?

- > a. There will be no difference in the number of disc rotations if the entire file were to be accessed by either I or II.
- b. Method I will be faster by one rotation than method II.
- c. Method II will be faster by one rotation than method I.
- d. Method I will be faster by two rotations than method II.
- e. Method II will be faster by two rotations than method I.

The following table is an example of

PATIENT Record			
		Subjects Who Know Password SICK	Subjects Who Know Password PAIN
Actions:	Read	Y	Y
	Insert	Y	N
	Modify	Y	N
	Delete	Y	N
	Grant	N	N

- a. Fernandez, Summers, Wood model of database security
- b. subject-orientated security
- > c. entity-orientated security
- d. all of the above

You are given the following table:

Relative Record Number	Student- number	Class- number	Semester
1	200	70	88S
2	100	30	89F
3	300	20	89F
4	200	30	88S
5	300	70	88S
6	100	20	88S

Determine which one is the correct inverted list (or index)

I.		II.		III.	
Student- number	Relative Record Number	Class- number	Relative Record Number	Semester	Relative Record Number
100	2	20	3	88S	1
100	6	20	6	88S	4
200	1	30	2	88S	5
200	4	30	4	88S	6
300	3	70	1	89F	2
300	5	70	5	89F	3

- a. I only
- b. II only
- c. III only
- d. I and II only
- > e. all the above

Management Supplemental Question 1

Level 1

A binary relationship involves at least two record types.

T or F  
^

Management Supplemental Question 2

Level 3

When the relationship is a 1:n and is mandatory in both directions, there is a strong likelihood that the records are describing different aspects of the same object.

T or F  
^

Management Supplemental Question 3

Level 3

An object relationship is one-to-one if:

- I. object A contains object B as a single-valued object property
  - II. object B contains Object A as a single-valued object property
  - III. object B does not contain object A
- 
- a. only condition I is necessary
  - > b. conditions I and II alone are sufficient
  - c. conditions II or III alone are sufficient
  - d. conditions I, II and III are all necessary

Management Supplemental Question 4

Level 3

If A is related to B and B is not related to A, it is referred to as 0:1 relationship.

T or F  
^

Management Supplemental Question 5

Level 3

The multi-valued attributes in a composite object never represent another object.

T or F  
^

Management Supplemental Question 6

Level 3



The keys of two relations having a compound-object relationship between them do not have a common attribute.

T or F

^

Management Supplemental Question 7

Level 1

An atomic transaction is

- a. any set of activities that operate on the same data-items
- > b. a set of activities that form one logical unit of work
- c. any set of activities that can be performed with one instruction to the DBMS
- d. any set of activities that can be performed concurrently

Management Supplemental Question 8

Level 2

To roll forward,

- > a. restore the database from a save and apply after images
- b. use the current copy of the database and apply the after images
- c. restore the database and apply before images
- d. use the current copy of the database and apply before images

- Management Supplemental Question 9

Level 3

A check point record is written

- a. after all updates have been made to the database
- b. after all requests have been written to the transaction log
- > c. after all requests have been written to the database and the transaction log
- d. before updates have been written to the database

Management Supplemental Question 10

Level 1

In the Fernandez, Summers, and Wood Model of database security, a subject can be

- > a. the program that will be processing the database
- b. the element of the database that will be protected
- c. the processing permissions given to a user
- d. the user's password

Management Supplemental Question 11

Level 2

Constraints on user's activity can be enforced by

- a. subject-oriented security
- b. object oriented security
- c. password matrices
- > d. user exits

Management Supplemental Question 12

Level 1

Functions of a DBA include:

- I. Management of data activity
- II. Management of database structure
- III. Database Personnel and Placement
- IV. Management of the DBMS

- a. I, II, IV only
- b. II and IV only
- > c. All of the above
- d. IV only

Management Supplemental Question 13

Level 1

Concurrent processing implies that the DBMS processes the queries of various users simultaneously.

T or F

^

Management Supplemental Question 14

Level 2

Serializability ensures that results of two concurrent transactions are the same as they would have been had they been processed one at a time.

> T or F

Management Supplemental Question 15

Level 1

Database changes that have been made by a transaction in process are said to be uncommitted.

T or F

^

Management Supplemental Question 16

Level 1

Concurrent processing does not lead to lost updates if transactions are only reading data.

T or F

^

Management Supplemental Question 17

Level 1

Deadlock occurs when each of two transactions is waiting for a resource the other has locked.

T or F

^

Management Supplemental Question 18

Level 1

Checkpoints are snapshots of updated parts of a database.

T or F

^

Management Supplemental Question 19

Level 1

The Performance Monitor maintains the configuration control of the DBMS.

T or F

^

Management Supplemental Question 20

Level 1

Interleaving means that while two or more transactions are processing concurrently the computer system executes some instructions from one, then executes some from the other, switching back and forth between them.

T or F

^

APPENDIX D  
COMPUTER-AIDED TEST QUESTIONNAIRE

LAST NAME \_\_\_\_\_ LAST FOUR DIGITS OF SSN \_\_\_\_\_

1. What are your general feelings toward this computer aided testing procedure?

very negative	somewhat negative	indifferent	somewhat positive	very positive
------------------	----------------------	-------------	----------------------	------------------

2. How do you feel that not being able to explain your answers affects the accuracy of the test?

very negatively	somewhat negatively	indifferently	somewhat positively	very positively
--------------------	------------------------	---------------	------------------------	--------------------

3. How do you feel about not having to answer essay questions?

very negatively	somewhat negatively	indifferently	somewhat positively	very positively
--------------------	------------------------	---------------	------------------------	--------------------

4. Did you feel more pressure with the computer test than you have usually felt during other written exams?

Yes or No

5. Rate your comfort level in using computers.

very uncomfortable	indifferent	very comfortable
	somewhat uncomfortable	somewhat comfortable

6. Do you think a computer aided exam tests the knowledge of the student more effectively than a written exam

Yes or No

7. Do you think that making such programs available for practice would help students learn subject matter better?

Yes or No

8. Please note any comments, likes/dislikes or recommendations you have about this test or the concept of computer aided testing in general?

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**APPENDIX E  
EXPERIMENT DATA**

STUDENT	SECTION	EXAM1	EXAM2	FINAL	COMPSCOR
1	1	40	43	56	2.34
2	1	49	47	76	4
3	1	48	43	59	3.34
4	1	46	46	46	2
5	1	50	42	51	2
6	1	46	41	59	3
7	1	49	45	64	3.34
8	1	39	41	64	2.67
9	1	42	48	74	4
10	1	47	47	60	2.34
11	1	45	45	74	3
12	1	44	37	45	2
13	1	48	44	70	3
14	1	48	47	67	3.34
15	1	45	46	58	2
16	1	47	45	74	3.67
17	1	49	43	68	4
18	1	46	40	52	2
19	1	43	43	38	1
20	1	33	45	55	1.67
21	1	34	38	45	1.67
22	2	47	48	72	3.34
23	2	43	42	57	2.34
24	2	48	49	65	4.34
25	2	44	46	75	3.34
26	2	46	43	60	3
27	2	39	45	55	3.34
28	2	44	44	61	3.67
29	2	43	46	51	2.34
30	2	48	48	72	3.34
31	2	49	46	75	3.34
32	2	43	41	68	3.34
33	2	38	43	51	2.34
34	2	39	43	48	1.34



STUDENT	QUEST1 GENLATT	QUEST2 XPLNANS	QUEST3 NOESSYQ	QUEST4 PCVDPRES	QUEST5 COMFLVL	QUEST6 PCVDEFCT
1	0	-2	0	1	2	1
2	0	0	2	1	4	0
3	-2	-2	-4	0	4	0
4	2	4	4	1	4	0
5	-2	-4	-4	0	4	0
6	2	0	-2	1	2	0
7	2	-2	0	0	2	0
8	-2	0	-2	0	-2	0
9	0	-2	2	1	4	0
10	0	0	2	0	2	
11	4	2	2	1	0	0
12	2	-4	4	1	2	1
13	2	-2	-2	0	4	0
14	2	0	4	1	4	0
15	2	2	2	1	2	0
16	4	-2	-2		4	1
17	4	2	4	1	4	1
18	2	0	4	1	0	0
19	-4	0	0	-2	0	0
20	0	-2	0	1	2	0
21	2	2	4	1	-4	0
22	4	-2	4	1	4	1
23						
24	0	-2	2	1	4	0
25	-4	-2	4	0	4	0
26	-4	-4	0	0	4	1
27	0	-2	4	0	4	0
28	-2	2	2	0	-2	0
29	-2	-2	0	0	-2	0
30	2	-2	4	0	4	0
31	-2	-2	0	0	-2	0
32	-2	0	0	0	4	1
33						
34	2	2	4	0	4	0

STUDENT	QUEST7	CTIME (MIN)	WTIME (MIN)	NUMQUEST
1	1	46	120	29
2	1	28	120	45
3	1	12	120	17
4	1	27	120	18
5	0	18	75	19
6	1	32	107	25
7	1	35	119	45
8	0	19	103	21
9	1	15	120	33
10	1	40	120	26
11	1	55	120	60
12	1	25	114	41
13	1	26	117	35
14	1	29	104	23
15	1	22	120	40
16	0	41	120	46
17	1	25	90	38
18	1	19	85	20
19	0	17	120	9
20	1	45	120	27
21	1	56	120	26
22	1	63	100	17
23		26	80	9
24	1	53	70	25
25	0	48	85	52
26	0	70	113	60
27	1	44	95	20
28	1	61	94	29
29	1	77	53	27
30	1	56	78	24
31	0	67	112	36
32	1	50	70	17
33		44	60	9
34	1	27	70	20

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